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Advanced QKD Protocols and Practical Challenges

Mohit Rajpurohit, Kaustubh Moni Deka, Vaibhav Pratap Singh, Haribabu P

Centre for Development of Advanced Computing - Bengaluru

C-DAC

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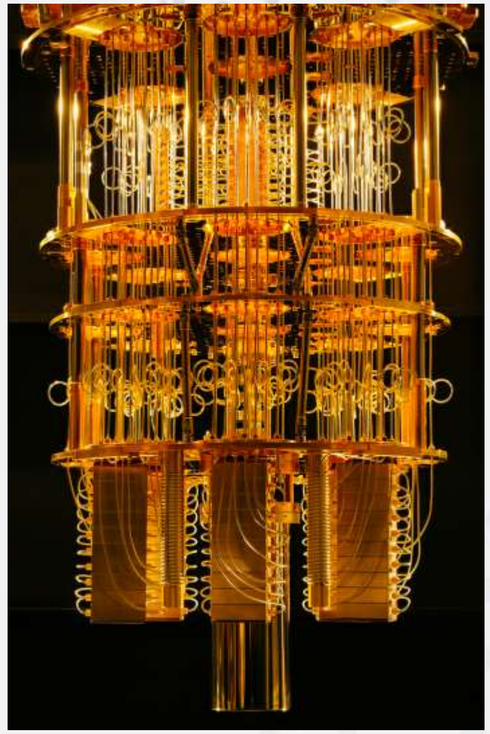
IEEE BANGALORE SECTION

Outline

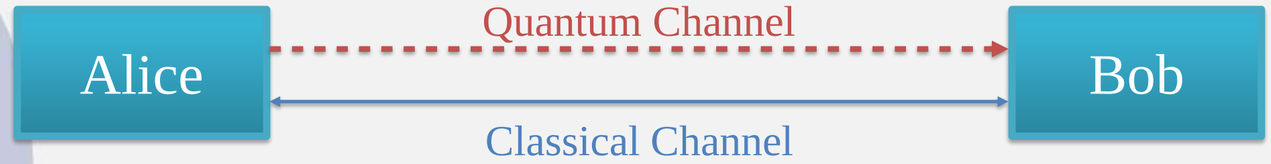
- ✦ Motivation
- ✦ Quantum Cryptography
- ✦ Advanced Quantum Key Distribution (QKD)
- ✦ Measurement Device Independent - QKD
- ✦ Twin Field - QKD
- ✦ Quantum Hacking
- ✦ Quantum Random Number Generator (QRNG) Integration
- ✦ Control Electronic Architecture
- ✦ Practical Challenges in Field Implementation

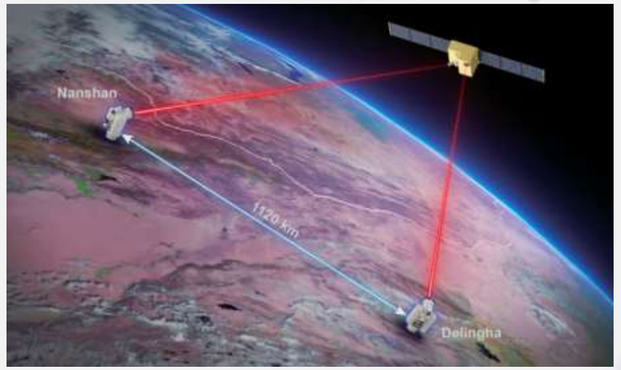
Prof. Richard Feynman

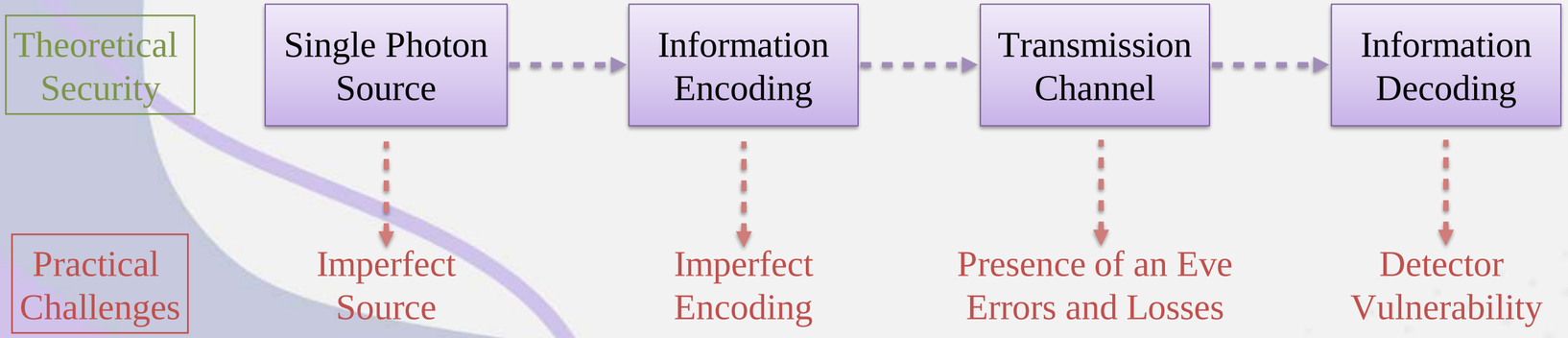


Quantum Cryptography

✦ Quantum Key Distribution (QKD) is a secure **Symmetric key** distribution technique whose **Unconditional Theoretical Security** is assured by the **laws of Quantum Mechanics**.







Measurement Device Independent - QKD

✦ It removes the Dependency from the Measurement Devices (Single Photon Detector)

Protocol

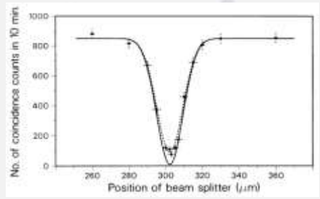
- **State Preparation:** Alice and Bob individually prepare a **phase randomized** weak coherent pulses(WCP) $|\sqrt{\mu_a}e^{i\theta_a}\rangle$ and $|\sqrt{\mu_b}e^{i\theta_b}\rangle$ with few different decoy intensities $\mu_a\ \mu_b \in [\mu, \nu, 0]$.
- **Measurements:** Alice and Bob send their quantum state to the **untrusted** third party **Charlie** to perform the **two photon interference** measurement on their state.

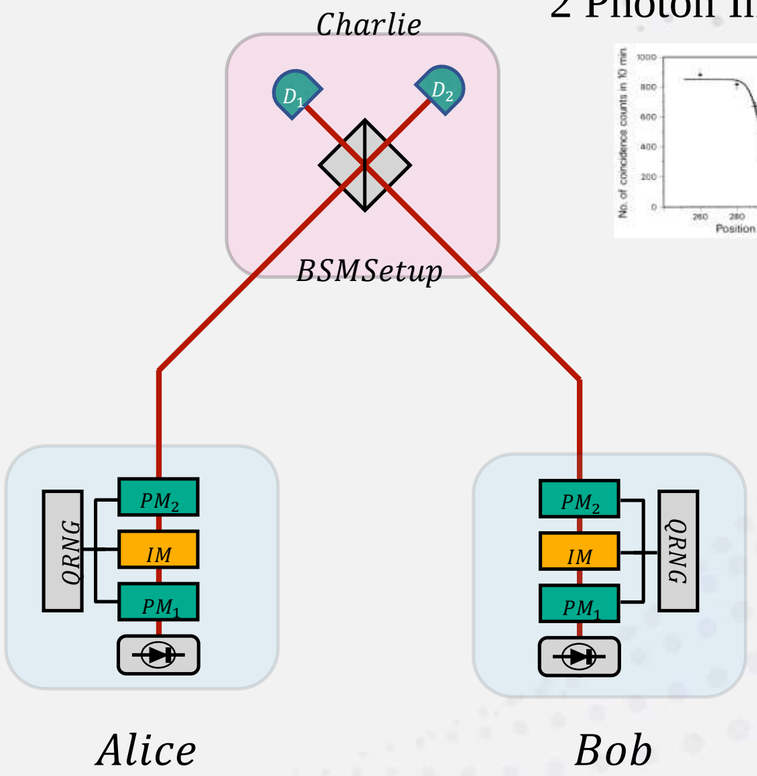
$$|\psi^-\rangle = \frac{1}{\sqrt{2}}[|01\rangle - |10\rangle]$$

Advantages

✦ Immune to all possible Detector based attacks
✦ A Star Type Network Topology
✦Sustain with High Channel Loss
✦ Untrusted Nodes
✦ Practicality

2 Photon Interference

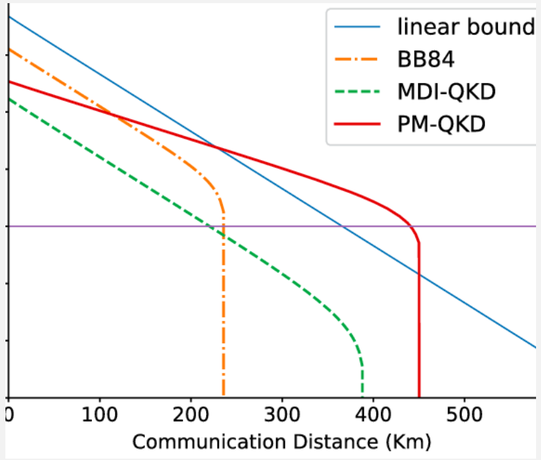


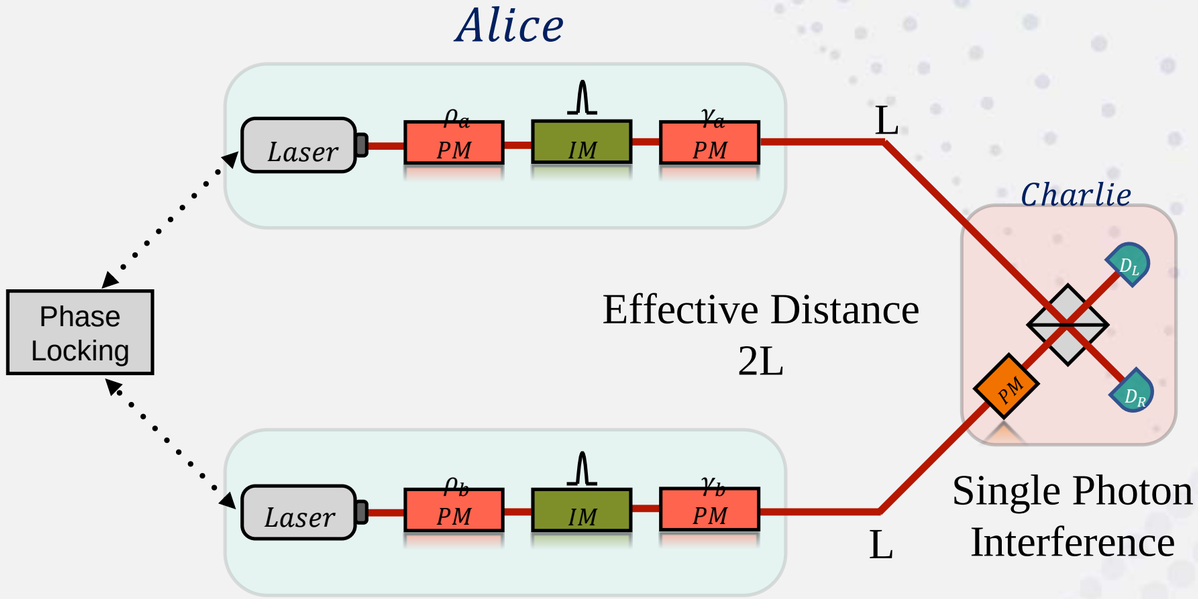


Twin Field - QKD

- The secret key capacity of a quantum channel sets an **upper bound** on the maximum extractable secret key, given by the **PLOB** bound…

$$R_{PLOB} = -\log_2(1-\eta)$$





Protocol

- **State Preparation:** Alice and Bob prepare a **Twin** like **Quantum Optical Modes**.
- **Measurements:** Alice and Bob send their optical modes to the central **relay station** Charlie. At the central, Charlie observes the **Single Photon Interference**.

Advantages

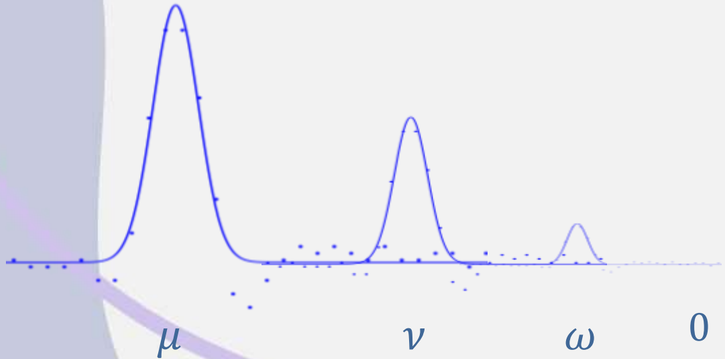
- All the MDI-QKD Features
- SKR $R \sim O(\sqrt{\eta})$

Quantum Hacking

- A **Weak Coherent State** can be described by a Mixture of **Fock states**.

$$|\alpha\rangle = e^{-\frac{|\mu|^2}{2}} \sum_{n=0}^{\infty} \frac{\mu^n}{\sqrt{n!}} |n\rangle$$

- By **Measuring** and **Monitoring** the **Parameters** of the QKD system, the **Leaked Information** can be estimated.



Decoy Intensities

- The **Imperfection** of the Practical devices leaves potential **Loopholes** for Eve to **SPY** the **Final Secret Key**.

Eavesdropper Strategy

Unambiguous State Discrimination (USD) Attack

POVM Measurement

+

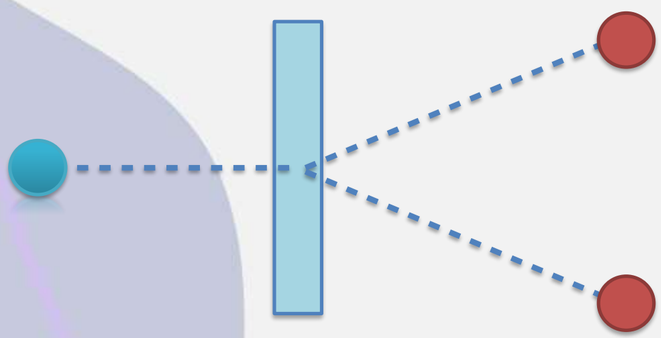
Photon Number Splitting (PNS) Attack

Multi Photon Emission

Solution

Phase Randomization Of Weak Coherent Source

Quantum Random Number Generator Integration



Heralded Single Photon Source

Beam Splitter

Bit 0

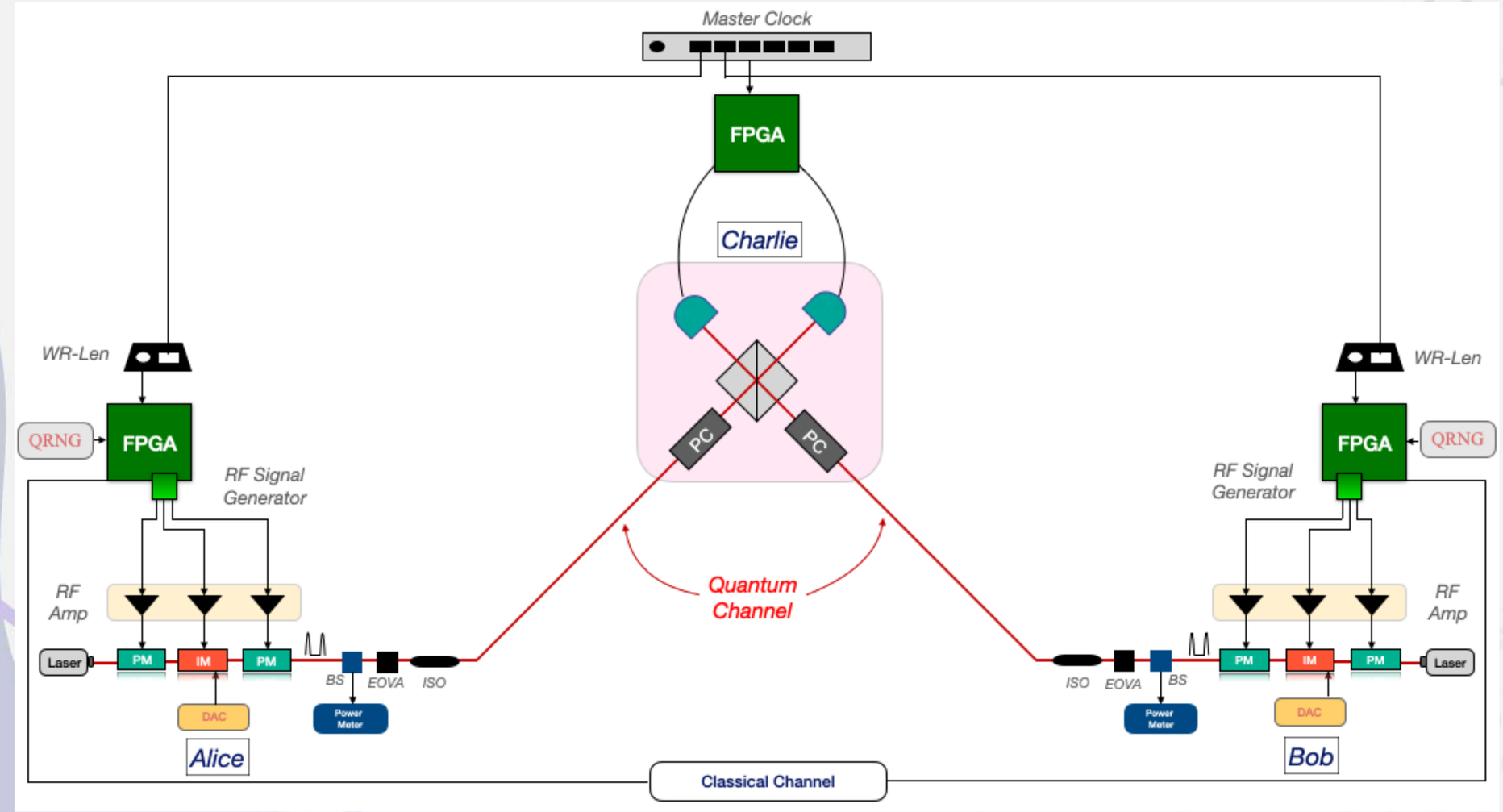
Bit 1

NIST Randomness Test

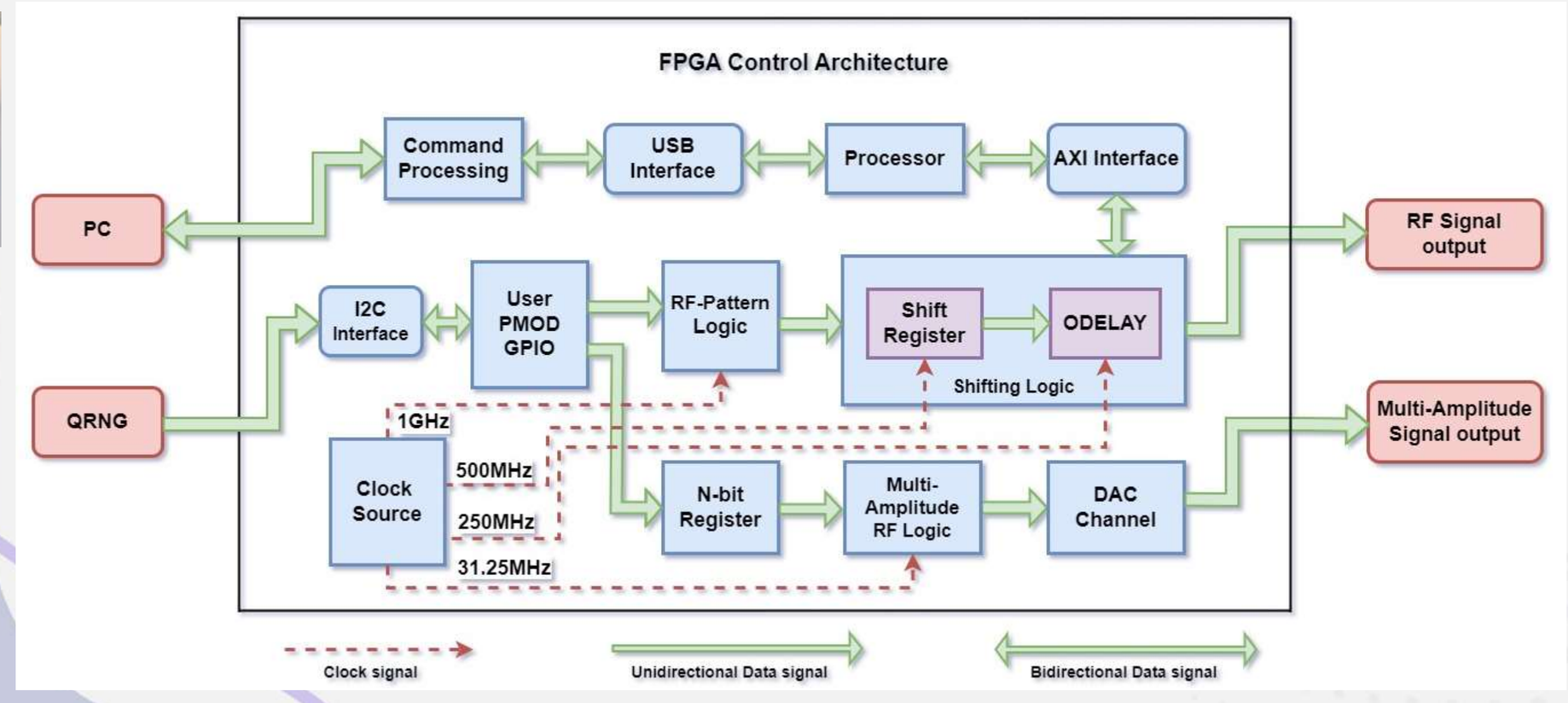
…	…	1	0	0	1	0	1	1

Random Bit String

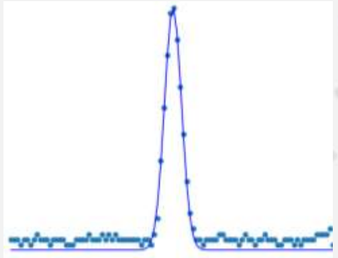
MDI-QKD Setup



FPGA Based Control Electronics



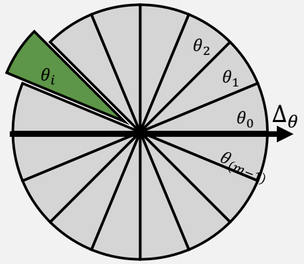
RF Signal



1 GHz Signal
Fine 4 ps Shifting

Experimental Results

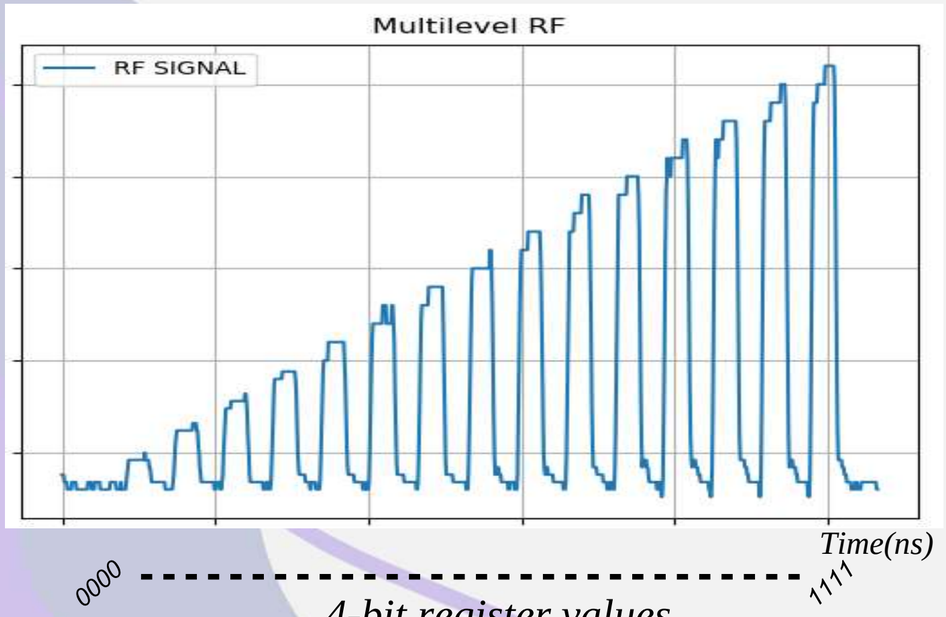
Discrete Phase Randomization

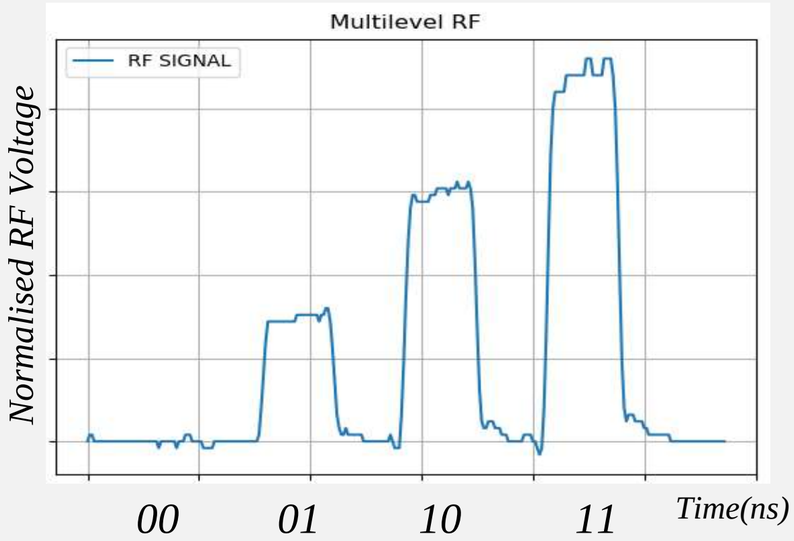


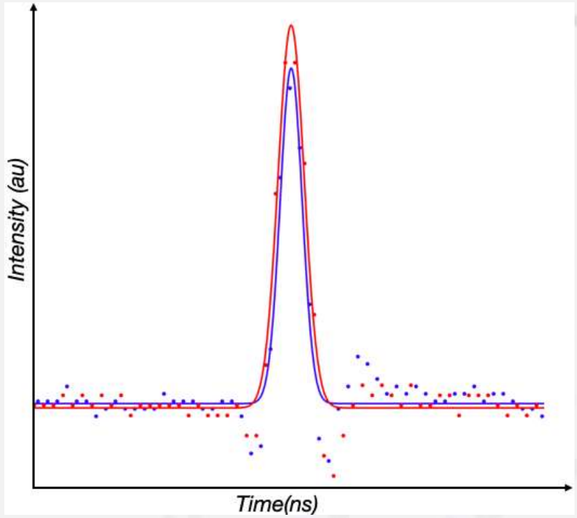
Phase Encoding

$$\left\{ 0 \quad \frac{\pi}{2} \quad \pi \quad \frac{3\pi}{2} \right\}$$

Phase Randomized Optical Signal







1 GHz Optical Signal

Devetek-Winter Bound

$$SKR \geq \frac{2}{M} Q_\mu [1 - H_2(e_p) - f H_2(e_\mu)]$$

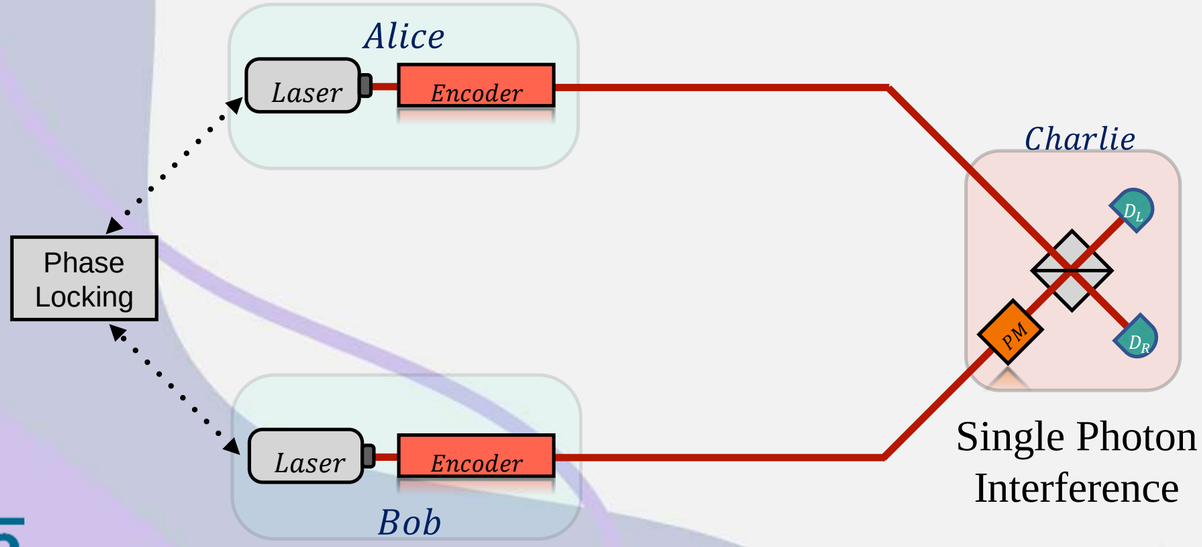
Practical Challenges in Field Implementation

Photon Interference

- Perfect **Temporal Overlapping**
- **Polarization** need to be Identical
- **Phase** of an Optical Signals need to be Correlated

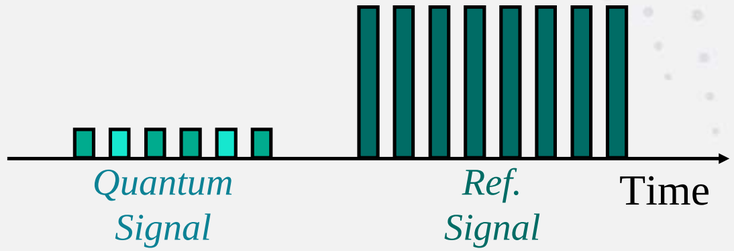
Phase Evolution

A. Phase of an **Optical Source**
B. Phase Introduced by **Optical Channel**



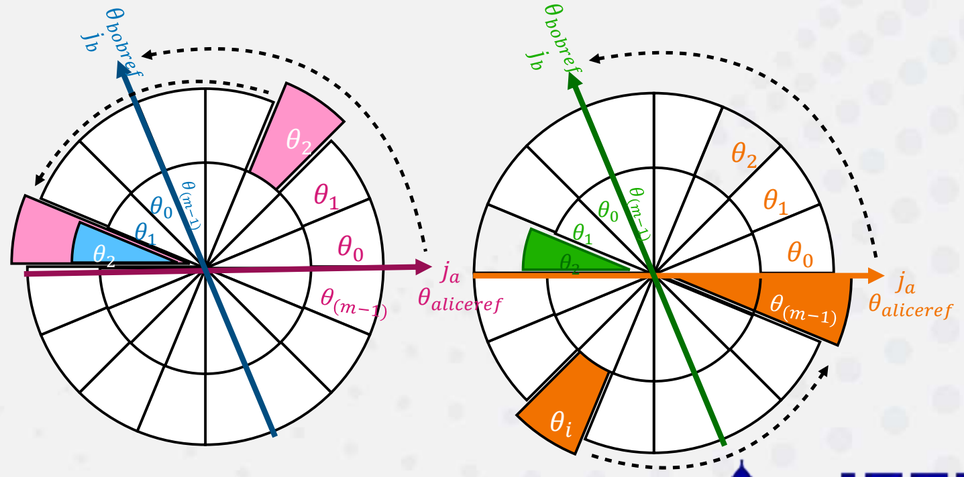
Single Photon Interference

1. No Phase Post Selection (NPP) Protocol



Time Multiplexed Signal

2. Phase Post Selection (NPP) Protocol



Conclusion

- **Experimentally** Generated a **Phase Randomised Optical Signal (Initial Quantum State)** using **Weak Coherent Sources** and **Electro Optical Modulators**
- Developed a **Control Electronics Hardware Design** based on **FPFG.**
- Detailed analysis of **practical challenges** for **field implementation**.

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